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Mississippi Basin Modeling System Development and Application

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Acknowledgements

This report documents the design, development and implementation of the Mississippi Basin Modeling System (MBMS) for real-time unsteady flow forecasting. Successful completion of this project hinged upon a team composed of individuals that blended geographical, technical, research and numerical model applications experiences. Many of the MBMS team members had participated in the prior study designs, model implementations and reporting of the Scientific Assessment and Strategy Team and the Floodplain Management Assessment study. The MBMS project developed and coalesced data acquisition and use, modeling software, communications, and reporting. Many ancillary issues such as data accuracy, physical feature modeling (e.g., levees and lock and dam structures), selection of appropriate mathematical modeling techniques, model calibration, etc. were addressed during this study.

Along with experience in the use of contemporary mathematical river modeling technology, a strong foundation of river engineering knowledge and experience was brought to this project by the team members. The primary participants from District and Division offices were: Stu Dobberpuhl (St. Paul Dist.), John Burant and S. K. Nanda (Rock Island Dist.), Jody Farhat (Northwest Division - Missouri River), Dan Pridal (Omaha Dist.), Rebecca Allison (Kansas City Dist.), Dennis Stephens (St. Louis Dist.), Stan Wisbith (Great Lakes and Ohio River Division), Don Flowers (Mississippi Valley Division) and Ron Hula (Southwestern Division). Technical support was provided by Tim Pangburn (Cold Regions Research and Engineering Laboratory), Ronnie Heath (Waterways Experiment Station) and Michael Gee (Hydrologic Engineering Center). Dr. Robert L. Barkau served as a consultant to the team and individually to several of the offices involved. Project management, guidance and coordination was provided by Ming Tseng of Headquarters Hydraulics and Hydrology Branch.

Chapter 1

Introduction

1.1 Background and Overview

The genesis of the Midwest Flood of 1993 was in a combination of extreme hydrometerological events. Precipitation during the winter of 1992-1993 was above normal throughout the upper Mississippi River basin and the lower Missouri River basin. This unrelenting rainfall, combined with an early snowmelt, produced high spring runoff. The wet-weather pattern persisted over the upper Midwest for about six months. The eastward-flowing jetstream became stationary; drawing warm, moist air from the Gulf of Mexico northward where it met the cooler air masses drawn southward from Canada. This situation resulted in successive occurrences of prolonged and excessive precipitation over the Upper Mississippi Basin leading to widespread, destructive, floods. These floods resulted in damages estimated at $12 to $16 billion (Interagency, 1994 - p. v), which were primarily agricultural. A detailed description of the hydrometeorology of the Midwest Flood of 1993 and its consequences can be found in (North Central Division, 1994).

Following the Midwest Flood of 1993 Congress tasked the Corps of Engineers to conduct a comprehensive, system-wide study to assess flood control and floodplain management practices in the areas that were flooded. That study was known as the Floodplain Management Assessment study (FPMA) (USACE, 1995). It encompassed three Corps of Engineer Division boundaries and five District boundaries. Participating Districts included; St. Paul, Rock Island, and St. Louis along the Mississippi River, and Omaha and Kansas City on the Missouri River. To accomplish the study objectives an unsteady flow model of the Upper Mississippi and Lower Missouri Rivers was developed. Each District developed independent models which produced results that were assimilated by neighboring Districts so that floodplain management alternatives could be evaluated systemically. The unsteady flow model was used to evaluate the potential impacts of various levee modification alternatives and upland watershed measures, such as reservoirs and land treatments, on the 1993 flood. The model selected for use in the FPMA study was UNET (HEC, 1997). It is a one-dimensional unsteady open channel flow simulation model that is further described in Section 3.

Structural flood protection measures performed as designed and prevented significant damages during the 1993 flood. The Corps, however, did not have a uniform, system-wide unsteady flow model specifically designed and implemented for the Missouri and Mississippi Rivers and their tributaries to analyze and predict system-wide impacts of various alternative actions during such flood events. The need for such a river model was identified in a Federal Interagency study chartered by the White House (Interagency, 1994):

> *"A system-wide unsteady-flow model of the main stem rivers in the upper Mississippi River Basin would help evaluate the impacts of proposed structures and floodfighting, and could be used for coordinated ecosystem modeling, and for floodplain management decisions. Further, advanced hydrologic and hydraulic models can be combined with meteorologic observations and forecasts to provide information to enable better floodplain and water resources management."* (Interagency, 1994 - p. 157)

The endeavor to develop such a model was initially known as the Mississippi River Forecast Model Development and is the subject of this report. The Corps team assembled to execute this effort was composed of representatives of the five Districts; St. Paul (MVP), Rock Island (MVR), St. Louis (MVS), Omaha (NWO) and Kansas City (NWK) involved in the FPMA study. Also included in this study were the Mississippi Valley Division (MVD), Great Lakes and Ohio River Division (LRD) and Southwestern Division (SWD). Technical support was provided by the Waterways Experiment Station (WES), Cold Regions Research and Engineering Laboratory (CECRL) and Hydrologic Engineering Center (HEC). Study management, guidance and coordination was provided by Headquarters Hydraulics and Hydrology Branch (CECW-EH).

The objectives for development of the forecast system were established based on past flood experiences and are listed here in order of priority: 1) Improve and facilitate the coordination, communication and sharing of data and forecasts among water control activities along the mainstem, 2) Assess impacts of levee breaching and floodway operations on local and downstream areas, 3) Support emergency management activities through timely prediction of river stage and rate of rise, 4) Display areal extent of flooding due to levee overtopping and/or breaching associated with various potential weather scenarios, 5) Identify navigation hazards and, 6) Provide data for real-time flood damage assessment. Several of the objectives listed above are based on needs identified in the FPMA report (USACE, 1995); particularly the first four. It is also important to note that many of the experiences and much of the data obtained during the FPMA study contributed substantially to the forecast model development. Although the primary objective of this work was the development and implementation of a UNET-based flood event forecasting system; that system was developed with the capability to also analyze low flows so that routine day-to-day forecasting needs and project operation activities can be accommodated as well.

1.2 Authority

Authorization and funding for this project was provided via CECW-EH letter dated 28 Feb. 1994, subject: Mississippi River Model Development. A comprehensive scope of work titled "Scope of Work for the Mississippi River Model Development" (dated 18 Feb. 1994) defined the features and functions of the Mississippi River (UNET forecast) Model. Subsequent acknowledgment by the working group of the large geographic

extent involved in this study led to the product of the effort being identified as the "Mississippi Basin Modeling System" (MBMS).

1.3 Summary of Work History

The work was performed in four phases. Phase 1 (FY 1994) consisted of assembling and testing data files by the local District offices. Phase 2 (FY 1995) focused on improving and expanding data and increasing the capabilities of UNET. Development of advanced hydrodynamic modeling techniques (e.g., two-dimensional for the floodplains) and use of data assimilation techniques for near real-time calibration were undertaken. Phase 3 (FY 1996) continued to refine data and UNET modeling capabilities. More emphasis was placed on integrating the MBMS modeling system into the real-time water control system. The fourth Phase, which ran concurrently with the others, was that of model support, maintenance and technology transfer.

1.4 Description of this Report

This report describes the history and status of the Mississippi Basin Modeling System development and application. Within this report, the term "model development" is sometimes used to describe software development and sometimes to describe data; i.e, its acquisition, preparation and use in the UNET modeling system and for calibration adjustments. The context of the use will clarify the distinction. Implementation of the UNET modeling system and ancillary software for real-time forecasting is described. Coordinations and collaborations that were essential to the success of the effort are reported. Data acquisition, calibration of the modeling systems, and its use for real-time forecasting are summarized.

Chapter 2

Mississippi Basin Modeling System Summary

2.1 MBMS Overview

The MBMS replicates and expands the functionality of the channel flow routing techniques used in day-to-day Corps forecasting activities. The MBMS incorporates advanced hydraulic routing, contemporary software technology, and was designed to accommodate future developments such as the products of the Water Control Data System (WCDS) modernization research program. There are several important technical differences between the MBMS flow routing and traditional hydrologic routing techniques:

- The routing module, which is used for the computation and prediction of discharge and stage hydrographs, is the full unsteady flow model - UNET (HEC, 1997).

- Because of the use of a physically based hydrodynamic model (UNET) any physical changes to the stream such as cross section changes, roughness changes, levee breaches, etc. can be depicted via physically based data with minimum reliance on empirical coefficients.

- Use of a physically based model increases confidence in simulated results for events outside the range of calibration events.

- Unsteady flow routing allows for the direct incorporation of backwater effects due to structures and tributaries in the routed hydrographs.

- UNET input and output is managed, processed, stored and disseminated via HEC-DSS (HEC, 1995).

- The system is uniform among the field offices; that is, the software suite, computational techniques, field data interpretation, calibration techniques and presentation of results are the same for all system users.

- The data bases, parameter calibrations, and system operation are applicable to planning and design studies as well as forecasting.

2.2 Geographic Coverage

The MBMS covers an extensive area; from Anoka, MN to the Gulf of Mexico on the Mississippi River, from Gavins Point Dam on the Missouri River to St. Louis (confluence with the Mississippi) and from Lockport Lock & Dam to Grafton on the Illinois River. Portions of numerous smaller tributaries in the Basin are also modeled as unsteady flow routing reaches. Also included (although not simulated with UNET at this time) are the Ohio River (LRD) and the Arkansas and White Rivers (SWD). A schematic representation of the system showing key locations that are referred to later in this report is shown on Figure 2-1.

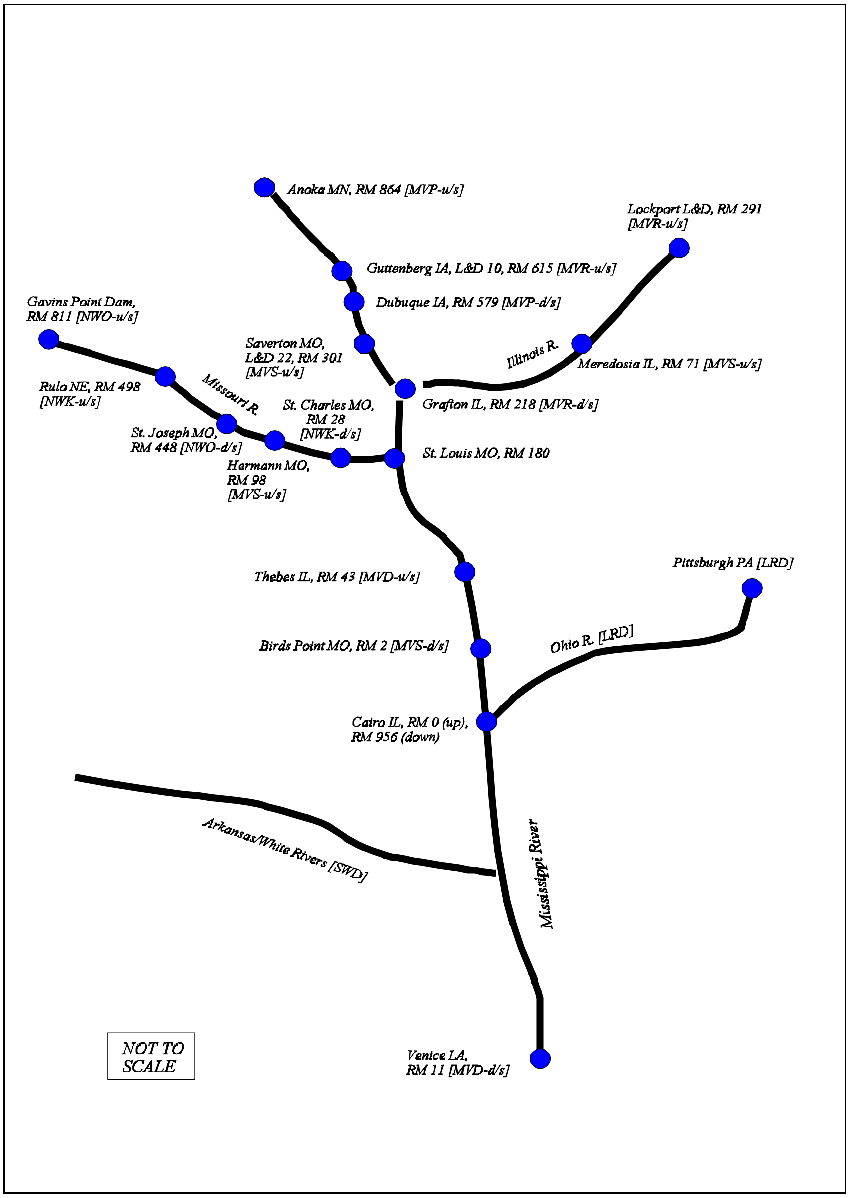

Figure 2-1. Schematic Diagram of MBMS Geographic Extent. (u/s = upstream location of UNET boundary condition, d/s = downstream location of UNET boundary condition.)

The main channel coverage by the various District offices is as follows: St. Paul District (MVP), Mississippi R. from Anoka, MN to Dubuque, IA (289 river miles); Rock Island District (MVR), Mississippi R. from Guttenberg, IA to Grafton, IL (314 river miles) and the Illinois R. from Lockport L&D to Grafton, IL (220 river miles); Omaha District (NWO), Missouri R. from Gavins Point Dam to St. Joseph, MO (313 river miles); Kansas City District, Missouri R. from Rulo, NE to St. Charles, MO (498 river miles); St. Louis District (MVS), Mississippi R. from Lock & Dam 22 tailwater at Saverton, MO to Birds Point, MS (299 river miles) and the Illinois R. from Meredosia, IL to Grafton, IL (71 river miles); Mississippi Valley Division (MVD), Mississippi R. from Thebes, IL to Venice, LA (987 river miles); Great Lakes and Ohio River Division (LRD), Ohio R. from Pittsburgh (PA) to the mouth; and the Southwestern Division (SWD), Arkansas and White R. basins which comprise about 189,000 sq. mi., of which about 156,000 sq. mi. contributes to stream flow.

2.3 Components

The MBMS consists of many individual components that may be grouped into data bases and software modules. Among the data bases are: (1) Measured field data such as cross sections and hydrographs, (2) Predicted (forecasted) inflows to the system such as runoff generated by a rainfall event, (3) Project operation criteria such as navigation dam rule curves, (4) Calibration data such as observed stage and flow hydrographs, (5) Simulation parameters such as Manning's *n* values and discharge-conveyance relations, (6) Computed forecast flow and stage hydrographs, and (7) Geographic Information System (GIS) data used for presentation of area maps, damage locations, gage locations, inundated areas, etc. The four primary software modules (each of which is composed of several sub-modules) comprising the MBMS are: (1) UNET, the one-dimensional unsteady flow hydrodynamic model, (2) A two-dimensional hydrodynamic model linked to UNET for overbank flow simulation, (3) HEC-DSS, the data management, manipulation and display module, and (4) the graphical user interface (GUI) that the forecaster uses to interact with the system. Also critical to successful operation of the MBMS are communication systems for the retrieval of real-time field data such as rainfall and gage readings, and the transmittal of forecasted information such as stage and flow hydrographs to other Districts and clients. The relationships among these components are depicted in Figure 2-2.

2.4 Forecast Operations

To produce reliable forecasts, the model must be calibrated to current conditions. The primary parameter that is calibrated is the channel conveyance. Adjustment of channel conveyance is considered to be the equivalent of adjusting Manning's *n* (assuming that gross channel geometric properties do not change). The concept implemented to date is that of performing a calibration outside of the real-time forecasting operation. Consideration may be given in the future to the use of real-time parameter adjustment schemes (data assimilation). At this time, however, the

calibration will be updated periodically, perhaps seasonally, rather than for each forecast. The sequence of steps used to obtain that calibration are:

1. Adjust conveyance to match USGS flows (base calibration).
2. Estimate ungaged inflows/outflows using the null internal boundary condition (Barkau, 1995).
3. Calibrate to intermediate gages.
4. Estimate, for locks and dams, the ungaged inflow between gages.
5. Calibrate to secondary gages.
6. Fine tune by adjusting to the individual event using the discharge-conveyance change factors.

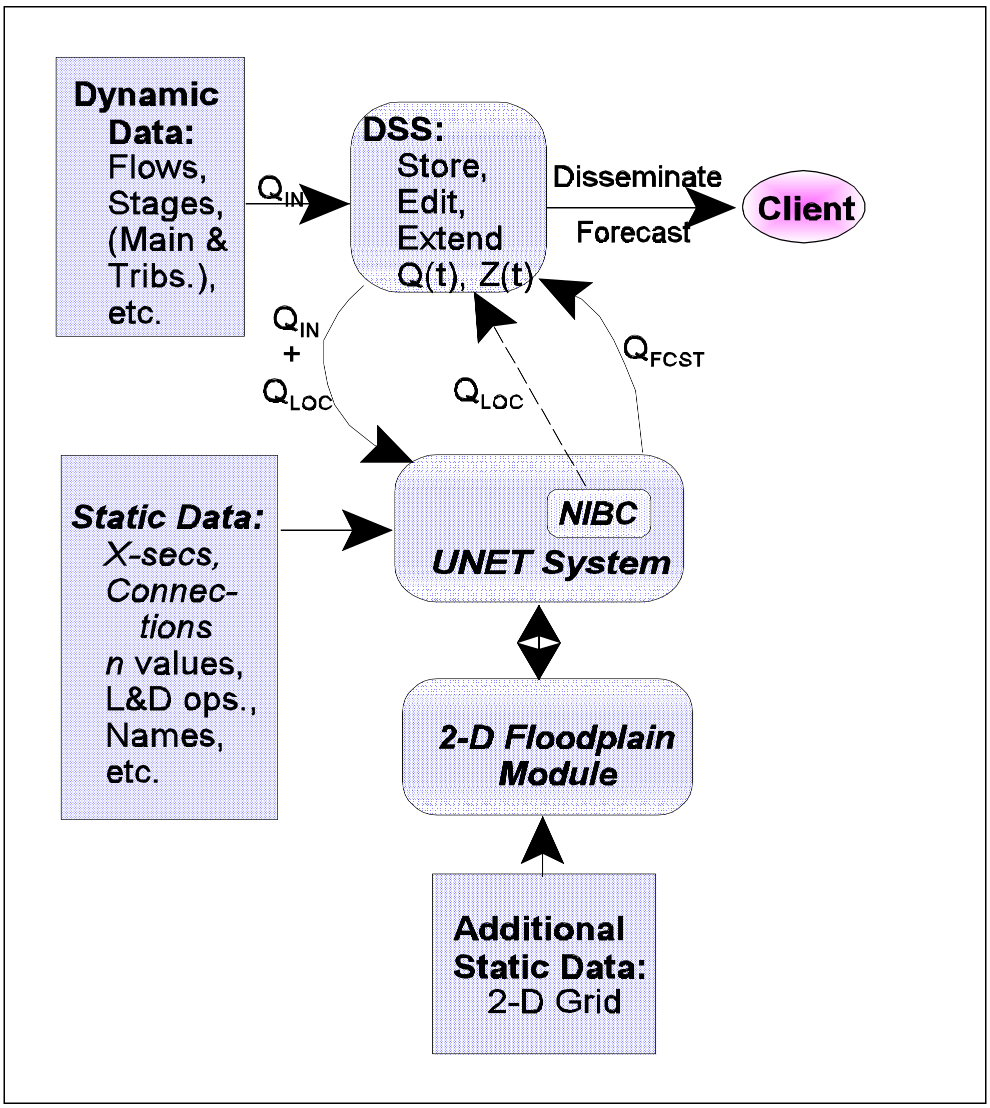

Figure 2-2. Components of the MBMS. NIBC = Null Internal Boundary Condition (Sec. 3.3.4).

Application of an unsteady flow modeling system to forecasting represents a significant departure from its use for simulation. Conceptually, the situation can be viewed as performing forecasting as usual, only using a more sophisticated routing technique. The need for uniformity among the offices, introduction of new technology and data systems to Water Control personnel, and requirements for timely and reliable forecasts required that significant effort be expended to develop and implement a GUI tailored for forecasting applications of the UNET system. The GUI is presented in more detail in Sec. 3.4.1.

Forecasting requires the introduction of the notion of “static” data. These are data that do not change each time that a forecast is prepared. In the UNET system, these data are primarily geometric (cross sections, energy loss coefficients, potential levee breach locations and parameters, etc.). Past observed and forecasted flows can also be considered static. What does change each forecast period are the inflows. The inflows for all inflow points must be obtained from the time of forecast (say 08:00 today) to the end of the forecast period (say 08:00 today plus seven days). These inflow values may come from application of a hydrologic model or extrapolation based on experience. The ungaged flows derived by implementation of the null internal boundary condition (NIBC - Sec. 3.3.4) must also be extended into the future. This relies on the forecaster’s experience and knowledge of the basins. Note, the flows used from the NIBC for the previous forecast may need to be updated to correspond with the observed flows during the period between the last forecast and the current forecast.

The static data may need to be modified periodically to reflect changes in river geometry or roughness. For example, the roughness characteristics of the Missouri and Mississippi Rivers change seasonally due to changes in water temperature, vegetation, and ice. This implies that the static data calibration may need to be updated periodically. This is best performed off-line (not as part of the routine day-to-day forecast operation) and blended into the forecast operation. Techniques and protocols for doing so will be developed during the initial use of the MBMS.

The MBMS is operational in all of the participating District offices and is being used for real-time day-to-day forecasting. By the middle of FY 1997 the system had seen use in real-time floodfighting. A detailed description of the implementation and use of the MBMS can be found in the St. Paul District report.

Chapter 3

The UNET Modeling System

3.1 Description

UNET (HEC, 1997) was the primary hydraulic analysis tool used in the FPMA study. It simulates one-dimensional unsteady flow through a network of open channels. One element of open channel flow in networks is the split of flow into two or more channels. For subcritical flow, the division of flow depends upon the capacities of the receiving channels. Those capacities are functions of downstream channel geometries and backwater effects. A second element of a network is the combination of flow; which is termed the dendritic problem. This is considered to be a simpler problem than the flow split because flow from each tributary is dependent only on the stage in the receiving stream. A flow network that includes single channels, dendritic systems, flow splits, and loops such as flow around islands, is the most general problem. UNET has the capability to simulate such a system.

Another capability of UNET is the simulation of storage areas; e.g., lake-like regions that can either provide water to, or divert water from, a channel. This is commonly called a split flow problem. In this situation, the storage area water surface elevation will control the volume of water diverted. That volume, in turn, affects the shape and timing of downstream hydrographs. Storage areas can be the upstream or downstream boundaries for a river reach. In addition, the river can overflow laterally into storage areas over a gated spillway, weir, levee, through a culvert, or via a pumped diversion.

In addition to solving the one-dimensional unsteady flow equations in a network system, UNET provides the user with the ability to apply many external and internal boundary conditions, including; flow and stage hydrographs, gated and uncontrolled spillways, bridges, culverts, and levee systems.

To facilitate model application, cross sections are encoded in a modified HEC-2 (HEC, 1990) forewater (upstream to downstream) format. A large number of river systems has been modeled using HEC-2; those existing data files can be readily adapted to UNET format. Boundary conditions (flow hydrographs, stage hydrographs, etc.) for UNET can be input from any existing HEC-DSS (HEC, 1995) data base. For most simulations, particularly those with large numbers of hydrographs and hydrograph ordinates, HEC-DSS is advantageous because it eliminates the manual tabular input of hydrographs and creates an input file which can be easily adapted to a large number of scenarios. Hydrographs and profiles which are computed by UNET are output to HEC-DSS for graphical display and for comparisons with observed data. Guidance for numerical modeling of river hydraulics is given in the River Hydraulics EM (USACE, 1993).

3.2 UNET Versions

UNET version 3.1 was released by HEC for general use at the end of FY 1996. That release contained substantial changes from the prior (ver. 3.0) release of UNET. Some added features included greater use of DSS for graphical displays, additional simple spillway connections, tunnel simulation, embankment breach simulation, more types of boundary conditions, etc. Documentation of those changes is available from HEC. Near the end of FY 1997 version 3.2 was released for general use. This version corrected some errors in ver. 3.1 relative to DSS reads/writes and embankment breaches. The user's manual was substantially improved in its correspondence with the software.

A common version of UNET (different from ver. 3.2) is being used by all of those involved with the Mississippi River Basin forecasting project. Note that the modifications to the "Mississippi version" of UNET, some of which are described below, are not in ver. 3.2. These modifications are considered developmental at this time; some are undocumented and some may not be of general use. HEC plans to include appropriate features of the Mississippi version in the next general release.

3.3 Developments to UNET During this Project

3.3.1 Levee Algorithms

The existing approach to simulation of the impact of levee overtopping and/or breaching on flood characteristics considers the area behind the levee to be a storage area. That is, it fills and empties through a levee breach or overtopped area, but does not convey water in the downstream direction. This concept of storage areas is used to blend one-dimensional and two-dimensional approaches to river modeling. For most situations, particularly with floods lesser than that of 1993, this is an adequate assumption.

The coefficients of the simple reservoir routing algorithm used in the existing UNET model to compute the flow through the levee breach can be fitted to observed data (hindcasting). Application of the UNET system to forecasting, however, should use coefficients and parameters derived as much as possible from field measurable information, rather than calibrated to past events. The routing coefficient that needs to be selected is the *k* in the equation:

$$Q_s = k\Delta V$$

where V is the volume of storage, Q_s is the flow of water to or from a storage cell (i.e., between cells or between the river and cell), ΔV is the volume to be filled or emptied and *k* is a linear routing factor with the units of time^{-1}. In the UNET model *k* can vary

among storage cells, but does not change with time nor with breach parameters such as width.

This description of levee breaches and the associated hydraulics is simplified. As a part of the MBMS development, research was performed to develop a physical interpretation of the linear routing coefficients (Shen and Zhao, 1995). This research involved comparing results using the storage area (linear routing) technique with those obtained using a fully two-dimensional hydrodynamic model. It was concluded that the routing coefficient required for the storage cell technique could only be accurately determined from past events and not from physical (e.g., topographic) data.

As a result of the 1993 flood on the Missouri River, a new capability for simulating the effects of levee breaches was added to UNET. During 1993 virtually all of the agricultural levees along the Missouri were overtopped, resulting in significant overbank conveyance. This situation poses a peculiar modeling problem. For flows below a certain transition discharge, the levee interior acts as a storage cell which communicates with the river through a breach, or breaches, in the embankment. When flow exceeds the transition discharge the area behind the levee no longer acts as a storage cell but becomes part of the river, conveying flow. Therefore, there are two situations that must be modeled; a storage cell and a flowing river. An algorithm was developed that allows the overbank storage areas to change to conveyance areas (and back) based upon a triggering river flow or stage. Consequently, the conveyance and storage of the levee cells is described by traditional cross section data rather than with a lumped routing coefficient.

Note, however, that these techniques do not directly <u>predict</u> the location, size, or timing of a levee breach. Once these parameters are known or estimated, however, the impacts of the levee breach on upstream and downstream flows and stages can be computed. Operationally, from forecasted stages, the forecaster may be able to hypothesize the locations and times of potential levee breaches and use the MBMS to rapidly evaluate impacts of various scenarios. Such an application would require that the possible levee overtopping and/or breaching parameters be built into the geometric data.

3.3.2 Dike Fields

A dike field is defined as a system of structures that contract the low flow cross-section to the design width of the navigation channel. UNET is one-dimensional; therefore, the local effects of each individual dike cannot be simulated. Rather, the cross-sections are contracted to simulate the contraction of the dike field. The area blocked by the dike field can be modeled as a storage area or as a dead area which is deducted from the cross-sectional area. The storage area simulates the condition where the area behind the dike has not filled with sediment and stores water. When the water exceeds the top of the dike, the storage area is assumed to return to active flow area, since the submerged dike field has little impact on the conveyance at high flow. Simulation of the added form roughness of the submerged dike is part of the

model calibration. The dead area simulates the condition when the area behind the dike has filled with sediment and both the conveyance and storage of that area are lost for all river stages.

3.3.3 Navigation Dam Algorithms

A major effort was undertaken to provide the ability to simulate lock and dam operations with the UNET system (Barkau, 1996). The capability to use operating rule curves at navigation dams as internal boundary conditions was developed and implemented. Preparation of the input data necessary to describe these rule curves was accomplished by the District offices.

Two types of navigation dam operation can be simulated:

Control point within the navigation pool. For this type of operation, the navigation pool is adjusted to maintain a constant elevation at a control point in the navigation pool. This procedure is also called hinge pool operation because the pool conceptually tilts about the control point. The hinge pool operation was devised to minimize the amount of flooded land that had to be purchased by the Government in the upper reaches of the pool. The operation of a hinge pool is defined by an operating curve (essentially a rating curve) at the dam. The operating curve is usually derived from experience. Operating curves are a set of functions which relate control point elevation to pool elevation at constant flow. An example of the operation criteria that can be prescribed by input data for a hinge pool is shown on Figure 3-1. It is abstracted from specific regulation curves for the locks and dams, which vary from structure-to-structure. Figure 3-1 portrays a hinge pool operation as used by the St. Louis District. In this case, the instruction to the lockmaster is to maintain a target pool elevation.

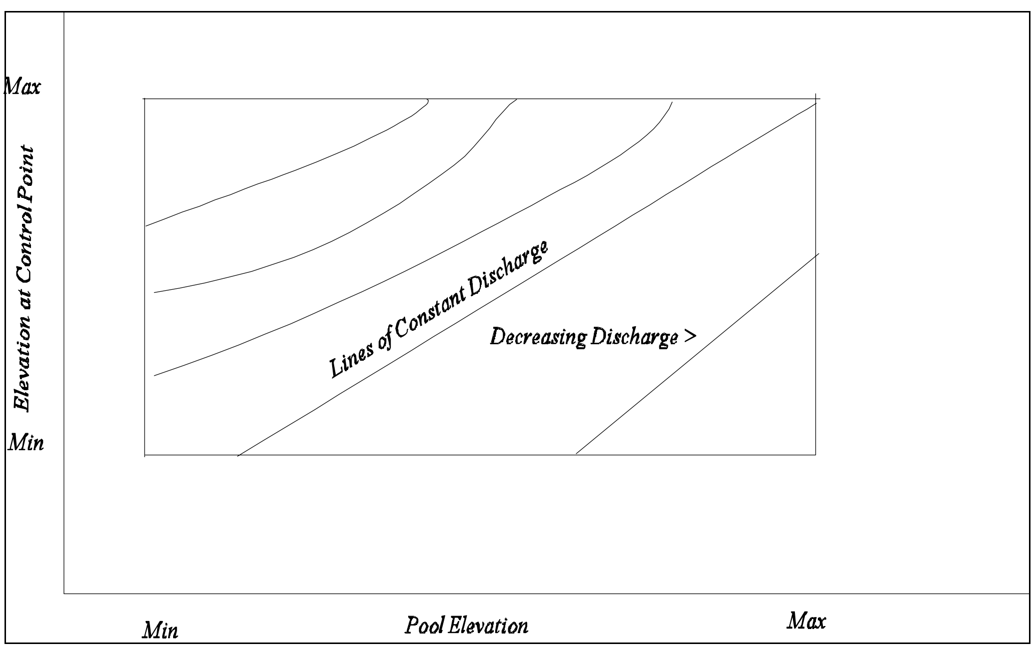

Figure 3-1. St. Louis District Operation.

Control point at the dam. This is the simplest regulation procedure for a navigation dam. The navigation pool is maintained at a target elevation at the dam. When the tailwater elevation plus the swellhead through the structure exceeds the target elevation, the pool is no longer controlled by the dam and the dam is in open river condition. The target elevation can change with the seasons. Figure 3-2 reflects a general operation as performed by the St. Paul District. For high flows tailwater controls (open river condition) and the difference between the pool and tailwater is the loss at the structure (swellhead). For lesser flows, gates are set to maintain a constant pool elevation. For low flows, the pool level is increased to maintain an upstream navigation depth. In this case, the lockmaster is given gate settings. Flexibility must be provided to allow for seasonal variations (ice, wind, etc.) and local requirements.

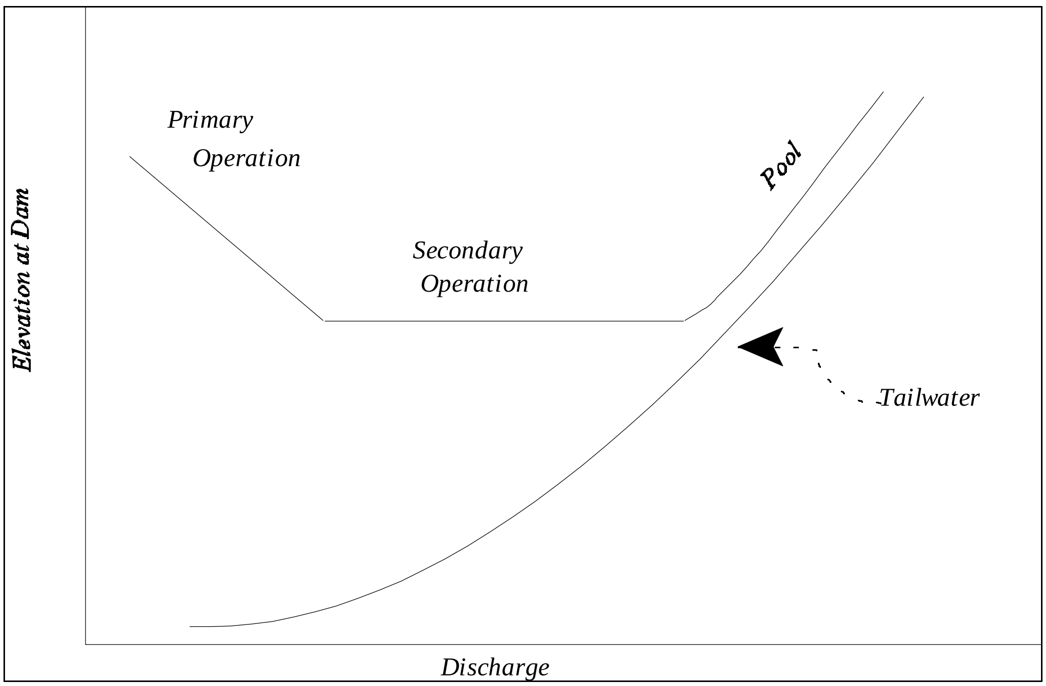

Figure 3-2. St. Paul District Operation.

The UNET navigation dam algorithm functions for two modes of application - simulation application and forecast application.

Simulation application. Under simulated operation, the navigation dam algorithm operates the dam exactly as specified in the regulation manual. At each time step, the UNET program (within the limits of computational, data and calibration accuracy) will exactly reproduce the target pool stage at the control point, whether that point is at the dam or within the pool.

Forecast application. Under forecast operation, the navigation dam algorithm will exactly reproduce pool stages at the dam until the time of forecast. After the forecast time, the program will either:

1. Simulate the target elevations as specified by the regulation manual.
2. Simulate target pool elevations as specified by the regulator.
3. Simulate an outflow hydrograph specified by the regulator.

The concept is to provide the forecaster with the information needed to make decisions quickly and easily.

The program MRGATE was also redone. The function of MRGATE is to provide suggested gate settings for a given flow; or, conversely, to compute a flow for given gate settings and water surface elevations. The program works from data definition files that describe the number, types, elevations and sizes of the gates for each of the structures so that appropriate hydraulic computations can be performed. Those files were developed by the offices responsible for the structures.

3.3.4 Null Internal Boundary Condition

The "null internal boundary condition" (NIBC) is a modification to the UNET system created by Dr. Barkau to estimate residual (incremental) flows (Barkau, 1995). These may be thought of as ungaged lateral inflows or outflows. The NIBC is inserted between two identical cross sections that overlay each other. The NIBC assumes that the flow and stage at the two cross sections are the same. For any reach of river of substantial length, the NIBC is applied at the principal gage locations where the stage records are the most accurate. This procedure uses two executions of UNET. The first assumes stage continuity at gages, with each gage location being an internal boundary condition. This results in computed flows both upstream and downstream of the gage, which will most likely differ. DSSMATH (an HEC-DSS utility) is then used to compute the residual flow (difference) for each reach between gages to achieve flow continuity at the gages. These residual flows are then distributed throughout the upstream reach (usually uniformly) and lagged in time as deemed appropriate. The second execution uses these flows as (uniform) lateral inflow hydrographs and removes the internal boundary conditions, resulting in an open river condition at the gages. This technique assumes that the model is well calibrated. It has been applied to the Kansas City District's reach of the Missouri River.

3.4 Migration to UNIX for Water Control Activities

The computer platform for water control applications is the Sun Sparc workstation with the Solaris operating system, which is UNIX. The development and application of the UNET system, however, has been on DOS personal computers. The HEC-DSS system has already been ported to UNIX as part of the real time water control R&D effort. A substantial effort was performed in FY 1996 to make the UNET system, with

recent updates to the software (levee breach algorithms, etc.) and the data, operational in the UNIX environment. Data files were tested and the proper interaction of the latest Mississippi version of UNET with the interface was confirmed. Many modifications to the UNET source code and file handling procedures were made. The UNET code, graphical user interface (GUI), data management and display systems continued to be developed throughout FY 1996 and 1997 as the system was adapted to the real-time forecasting work environment. Substantial effort was expended by HEC and CECRL working with individual field offices to customize the GUI for local place names, etc.

3.4.1 Graphical User Interface

The GUI developed for the MBMS was based on work done by the Corps Cold Regions Research and Engineering Laboratory for the Missouri River Division. That work involved management of releases from mainstem Missouri River dams to ameliorate endangered species habitat. It was primarily a “simulation” application. That interface was expanded to meet the needs for forecasting applications. The enhancements to the interface included; consistent file management, implementation of a UNET hotstart capability, easy time window selection, and interaction with DSS-DSPLAY in a fashion consistent with water control needs. The GUI runs under UNIX. Figure 3-3 shows an entry window. The GUI also interfaces with a geographic information system (GIS) to provide map-based interaction with the data displays.

Figure 3-3. MBMS GUI Entry Screen.

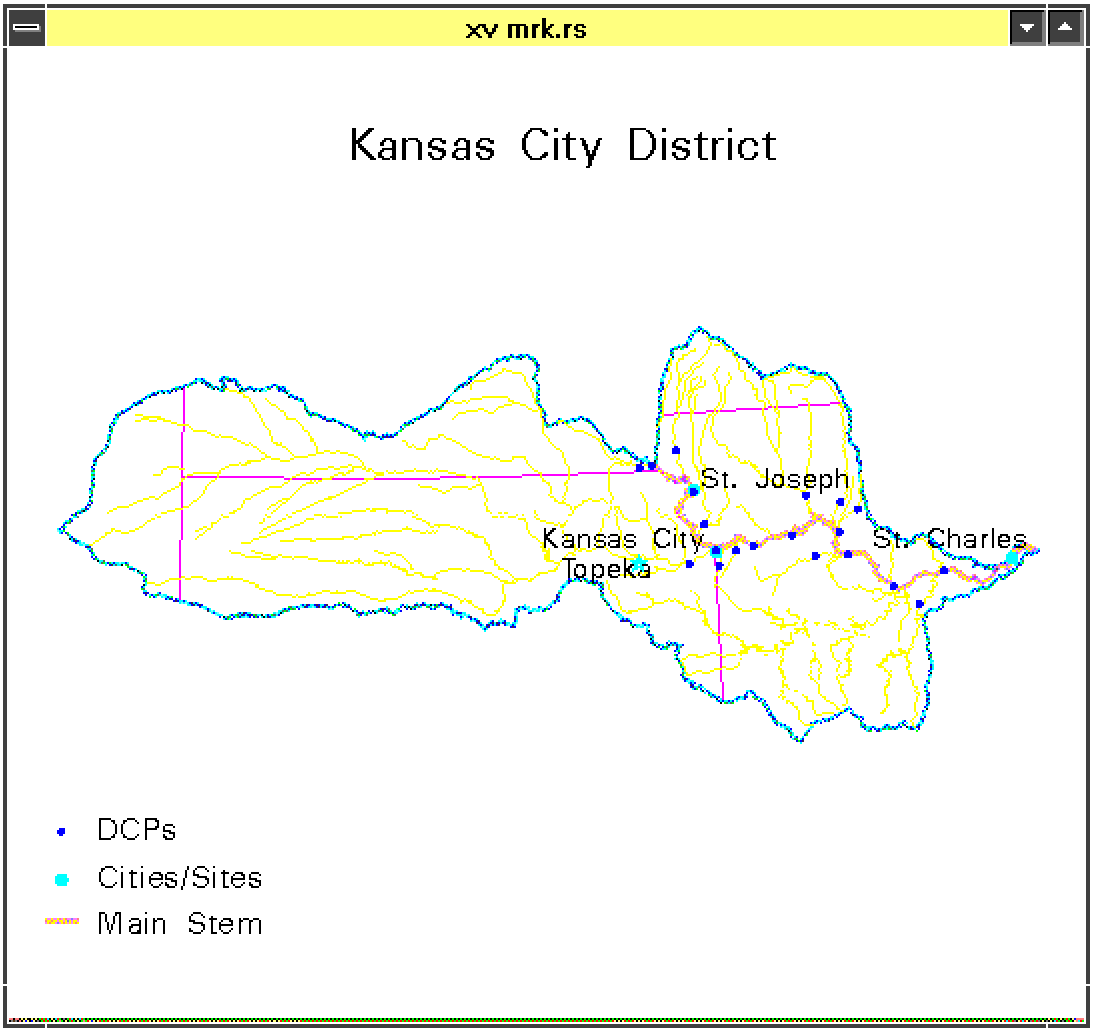

Figure 3-4. Example Display of a Drainage Basin from the GIS.

Figure 3-4 shows an example of such a display. These displays are active in the sense that access to DSS data can be obtained by clicking on a location of interest.

Figure 3-5 shows the screen presented upon selection of the "Model" button on the entry screen. This screen provides the user with identification of the static data currently in use (River ID, CSect Template, and BC Template). The time period represents the entire simulation period which includes a warm-up period prior to the time of forecast and the forecast period. The warm-up period is used to blend in any changes to the system that have occurred since the last forecast. An example would be updating the extrapolated local inflows to match the flows based on observed data from the last time of forecast to the present one. The execution of the UNET system is launched from this screen via the "Run UNET" button.

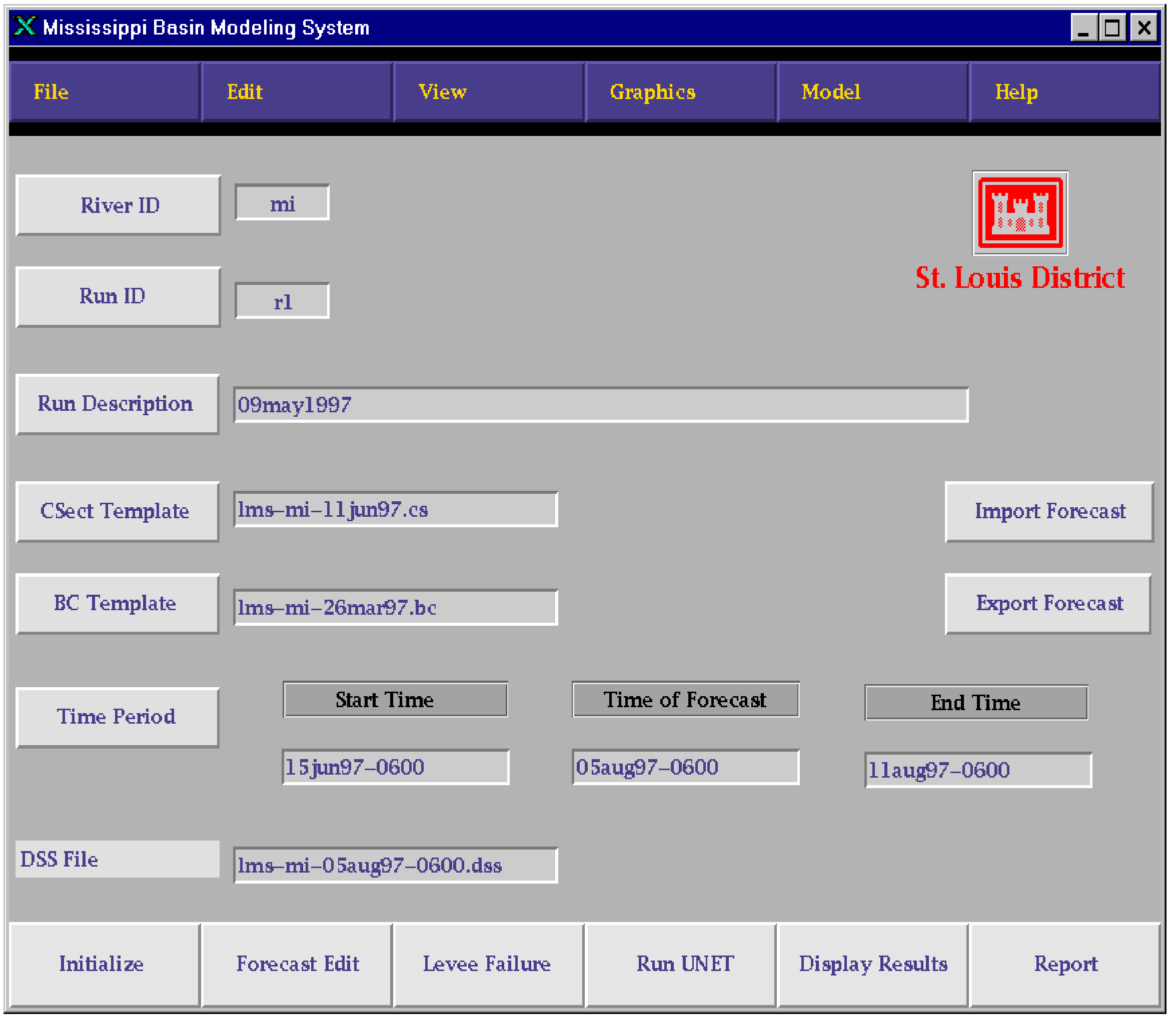

Figure 3-5. MBMS GUI Screen Obtained by Selecting the "Model" Button on the Entry Screen.

The "Forecast Edit" button allows the forecaster to edit the forecasted flows either graphically or by entering their new values. The "Display Results" button allows selection of a gage station, location or profile for display of computed hydrographs or water surface profile elevations. The "Levee Failure" button generates a scrollable display of the levees defined as having potential for overtopping/breaching. Breach parameters, such as time of initiation, can be interactively changed from this screen. Most of the GUI data edit capabilities are essentially DSS-DSPLAY operations and, therefore, are familiar to HEC-DSS users.

The GUI is operational at all District offices involved in this study. The GUI files have been customized by CECRL and HEC to include local gage names, river names, etc. District H&H personnel have worked with CECRL and HEC personnel to transfer this technology to local water control units. The GUI and the MBMS hydrodynamic software are uniform among the Districts. In addition to using utility software that was developed prior to the MBMS development and implementation, custom support software for data acquisition and transmittal has been developed by some offices.

3.5 Two-Dimensional Modeling Capability for Overbank Areas

An accurate description of combined channel and overland flood flow requires a blend of one- (1-D) and two-dimensional (2-D) surface water flow modeling concepts. Two-dimensional computations in a floodplain can range from being fully 2-D and dynamic to consisting of only a few large storage cells with momentum effects completely neglected. For example, through the use of storage cells, UNET provides a method to account for floodplain storage and allows a highly skilled modeler to approximate kinematic floodplain routing through a coarse network of storage cells. A recent evaluation of surface water flow models by WES suggested that it is possible to link 1-D channel flow models, such as UNET, with a 2-D finite volume overland flow model. The overall objective of this task has been to develop the 2-D model and then to formulate, implement, and test a linkage methodology which will allow combined channel and overland flood modeling. This methodology permits 2-D dynamic routing of flows across a floodplain represented by moderate to high resolution finite volume grids. The same linkage methodology could be applied to a number of different 1-D and 2-D routing models.

The 2-D floodplain routing model is similar to UNET in that conservation of mass and momentum equations are solved. For purposes of model flexibility, however, an explicit numerical solution has been selected. The 2-D finite-volume method divides the system into an unstructured grid of cells where stage is defined at the center of the cell. Flows are defined along one-dimensional channels that link the centers of the finite volume cells. The basic concept is illustrated in Figure 3-6.

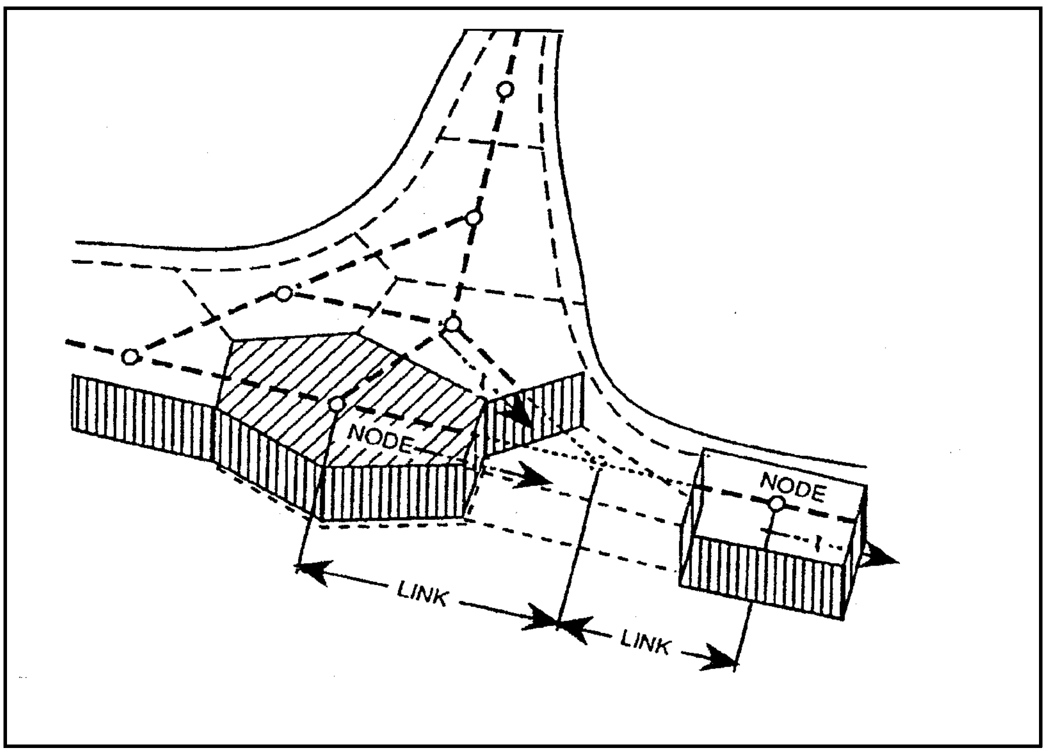

Figure 3-6. Depiction of Finite Volume Method.

In general, the 2-D finite-volume model solves one-dimensional equations in the channels for the conservation of momentum with the subsequent conservation of flow volume being determined by summing flows across the sides of the 2-D finite volume cells. This approach has three major assumptions: 1) the flow is predominantly unidirectional along each channel, 2) Coriolis and other accelerations normal to the direction of flow are negligible, and 3) individual channels have uniform cross-sectional areas. One feature of the 2-D finite-volume formulation is that it is easy to represent hydraulic structures such as culverts, weirs, and gates, by replacing the momentum equation with the appropriate hydraulic structure equation. The resulting system is highly flexible because complex geometries of interlinked waterways and overbank areas can be easily represented, and solving a series of 1-D momentum equations along with the 2-D continuity equation provides an efficient solution scheme for long-term simulations.

The linkage between UNET and the 2-D floodplain model was evaluated by WES via a series of idealized grid and interior boundary condition tests. These tests demonstrated that the coupling between the two models performed well in a highly stable manner and that flow volume was conserved. Following these tests, a 2-D model grid, Figure 3-7, was developed representing a portion of St. Charles County, MO, where cross-basin flows from the Missouri River into the Mississippi River occur during large floods.

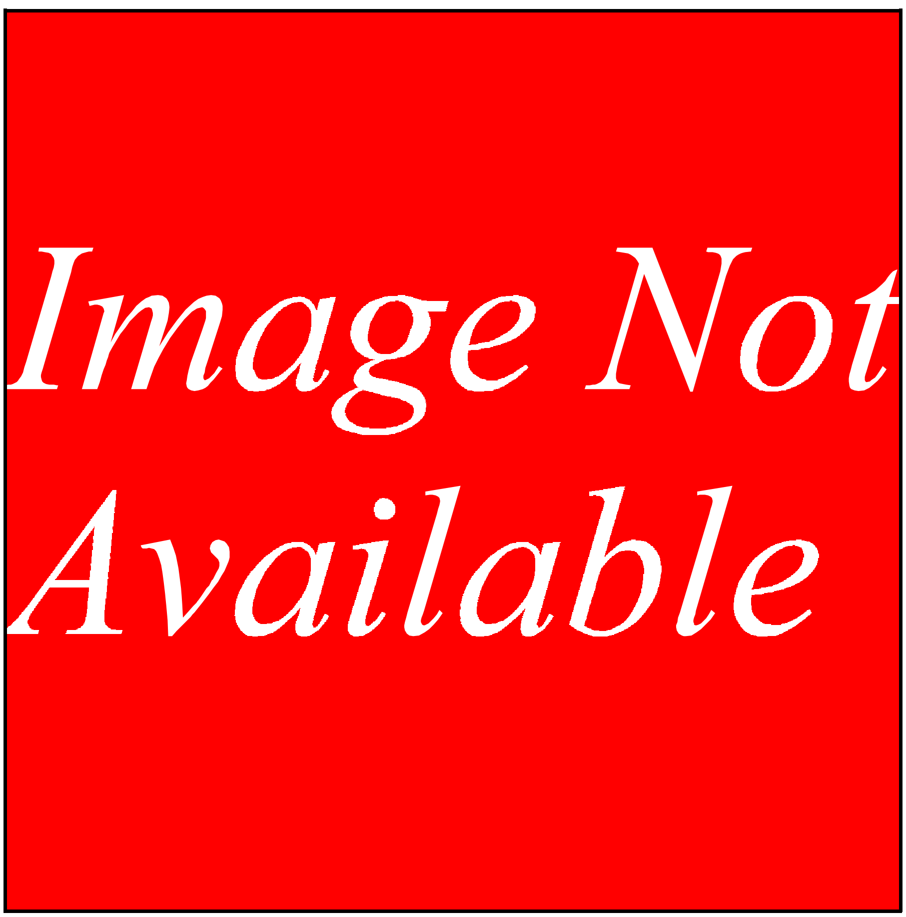

Figure 3-7. Two-Dimensional Model Grid for Crossover Area.

Typically, cross-basin flows in this system occur when agricultural levees along the Missouri River overtop and/or breach, resulting in a significant diversion of flow into the Mississippi River. After levee crevassing occurs, the diverted flow is controlled by a railroad embankment that extends from high-ground in the vicinity of Orchard Farm, Missouri, downstream to West Alton, Missouri. Experiments conducted with the 2-D floodplain model revealed that the computed diversion hydrograph was sensitive both to assumed levee breach characteristics and the hydraulic geometry of the railroad embankment. Reliable forecasting of the diversion flow hydrograph will require research to improve methods for computing flow through levee crevasses. Subsequent to development of this model, high-resolution digital terrain models of the study area, including embankment profiles, have been developed which could be used to develop a more detailed and extensive 2-D hydraulic floodplain model representing existing conditions.

A second 2-D floodplain model representing the Birds Point-New Madrid Floodway, Figure 3-8, has been developed and linked to the Ohio River Forecast Model[1]. The 2-D floodway model is being used to simulate operation of the floodway during a hypothetical project flood. Floodway operation is a complex undertaking which includes phased creation of levee crevasses at multiple locations and overtopping of fuse-plug segments at both ends of the frontline Levee separating the floodway from the Mississippi River. The floodway is also subject to backwater flooding through a gap between the setback and frontline levees at the lower end of the floodway. Determination of interior stages and flow distribution with a 1-D unsteady flow model would be very difficult given the irregular shape of the floodway boundary combined with multiple inflow/outflow locations. Many previous studies of the floodway were conducted using a large-scale physical hydraulic model, the Mississippi Basin Model (MBM), which has been retired from service. The 2-D floodplain model permits direct computation of spatially distributed stage and flow at a horizontal resolution of 300 to 1000 meters (with better resolution possible at the expense of greater computational time). Floodway inundation from both backwater flooding and levee crevasses may be visualized by creating animations directly from the stage computed by the 2-D model.

3.6 Use of GIS for Inundation Mapping

The integration and use of geographical information systems (GISs) and digital elevation models (DEMs) to develop, interpret and present the results of hydraulic modeling is available to users of the MBMS. Much of the software and data that are available was developed external to the MBMS *(Fry and Dozzi, 1997)*. A key component of the GUI development was the incorporation of existing GIS sources into the use of UNET for the MBMS (see Sec. 3.4.1).

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[1]The Ohio River Forecast Model is a 1-D unsteady flow model of the Ohio River, its major tributaries, and relevant portions of the Mississippi River that was developed by the WES in the early 1980's and subsequently enhanced by the Ohio River Division Reservoir Control Center (RCC). The model has been used as a forecasting tool since its delivery to the RCC in 1984.

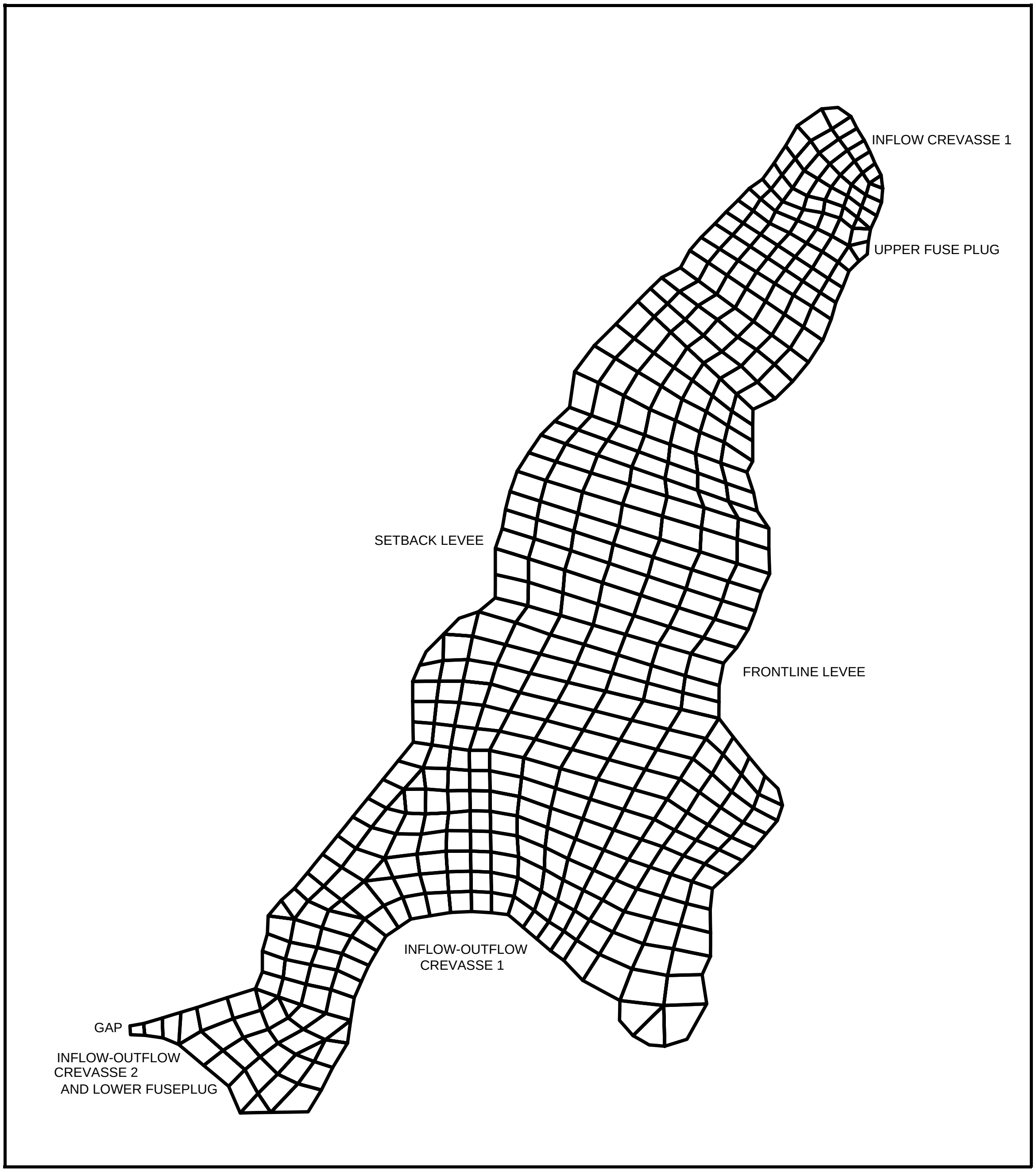

Figure 3-8. Two-Dimensional Grid Representing the Birds Point-New Madrid Floodway.

Chapter 4

History of Coordination and Contracting

The Mississippi Basin Model System development team consisted of representatives of the four Divisions involved (NWD-MR, LRD, MVD and SWD), active Districts (MVP, MVR, NWO, NWK and MVS), laboratories (HEC, CECRL and WES) and HQ. Dr. Barkau served as a consultant to the team and individually to several of the offices involved. It is anticipated that future coordination will expand outside of the Corps to include the National Weather Service and, possibly, others.

This application of UNET to the Missouri-Mississippi system also provided an opportunity to coordinate with ongoing R&D activities. In particular, the Water Control Data System (WCDS) Corps-wide software modernization research program will provide the framework within which this model will be used in the future. The UNET system will become integrated with the real-time water control system as a computational tool to perform flow routing and stage prediction for project operations. The components of the WCDS work involving graphical user interfaces and spatial displays of precipitation and inundated areas will support UNET forecasting applications. WCDS coordination meetings that were held at HEC approximately monthly during the latter part of this study included reporting of the status of the Mississippi Basin forecasting effort. Additionally, the HEC River Analysis System (RAS) is being developed such that UNET can be incorporated as its unsteady flow solver. Several meetings were held with Dr. Barkau to design HEC-RAS's management and use of geometric data to be consistent with UNET. These efforts continue to progress simultaneously, with interaction among the several teams.

Coordination and data exchange was also accomplished with the Corps Floodplain Management Assessment (FPMA) teams and the interagency Scientific Assessment and Strategy Team (SAST) (Freeman and Frazier, 1997). These were two complementary efforts to study the impacts of levees on the Missouri-Mississippi river system. The former used UNET to analyze the effects of an array of levee placement options on flood heights and the latter used an interdisciplinary approach to evaluate the consequences of levee placement on wetlands, environmental quality, agricultural use, local economies, etc.

4.1 Coordination Activities (FY 95)

Following is a summary of the UNET forecast team meetings held during FY 1995. In general, these meetings served three purposes: 1) Share with the group the status of each element's work, 2) Identify problem areas and potential resolutions, and 3) Identify near term schedules and goals.

19-22 Sept. 1994 in CEMVD. A workshop was presented by Dr. Barkau on the subject of calibration of the various portions of the Mississippi Forecast Model.

24-27 Oct. 1994 in NWD-MR. Discussions of use and selection of boundary conditions and model overlap areas (see Section 6) between offices.

29 Nov.-1 Dec. in MVS. Developed plans for involving Dr. Barkau to upgrade the UNET model being used by Mississippi River analysts to include various levee breach algorithms and lock and dam operations. Presentation of CECRL UNET model GUI.

24-25 Jan. 1995 in MVS (SAST mapping). Meeting to prioritize data acquisition for both 2-D and 1-D modeling of the Missouri-Mississippi system.

6-8 Feb. in LRD. Focus was the use and operation of LRD's forecasting system for the Ohio River which uses an unsteady flow model (FLOSED).

25-26 May in MVR. Reporting on status of UNET applications for FPMA, WES 2-D application and data assimilation design.

10-13 July in Ft. Collins, CO. Focus was the design and details of operation and presentation of the UNET forecasting system.

28-30 Aug. in CECRL. Focus was on migration of the UNET system to the Sun Solaris workstation and execution of the system with the three primary data files of interest (MVR, NWK, and MVS). Presentation of the "null internal boundary condition" by Dr. Barkau. This feature was designed to compute residual flows.

12-13 Sept. in HEC. Focus was on developing an operational demonstration using HEC equipment. The presentation included involvement of HEC water control staff.

4.2 Coordination Activities (FY 96)

Following is a summary of the UNET real-time forecast team meetings held during FY 1996.

24-26 Oct. in MVS. This meeting was to tailor the applications; both UNET and the GUI, to forecasting. Accomplished were the design of data naming conventions and system execution protocols that support the real-time forecasting environment. A real-time oriented GUI design was developed.

6-7 Feb. 1996 in MVS. Design of specific modifications to UNET to simulate and facilitate the operation of lock and dam projects, particularly on the Middle and Upper Mississippi River.

13-15 Feb. in CECRL. Testing of changes to the GUI that were defined at the 24-26 Oct. meeting. Kansas City District's data files were used.

28-29 Feb. in NWK. General meeting of the working group to communicate and coordinate activities and plans for FY96 and FY97. Preliminary planning for a demonstration of the system in the Washington D.C. area (HQ) to Corps executives and the NWS.

11-13 March in MVS. Working meeting to test use of the GUI with Rock Island, Kansas City and St. Louis data sets and continue planning for the demonstration.

2-4 April in MVS. Working meeting to further test and understand the use of the GUI and data transfer by Rock Island, Kansas City and St. Louis. Performed live data transfer of forecasts from upstream Districts to downstream Districts and used those data to prepare forecasts by downstream Districts. This effort included use of a remote site (Rock Island).

15-17 July in Washington DC. Presentations and demonstrations of the UNET forecasting system using 1993 data to HQ H&H staff, HQ executive staff and other agencies (see Sec. 6).

6-7 August in MVP. Meeting to review progress of Dr. Barkau on development and implementation of new lock and dam algorithms for UNET. Also prepared a preliminary formulation of detailed FY97 activities and budgets.

4.3 Coordination Activities (FY 97)

Following is a summary of the UNET real-time forecast team meetings held during FY 1997.

24-25 Oct. 1996 in New Orleans. Meeting to discuss and finalize several issues in preparation for closure of the project at the end of the FY. Some of these items were; provide suggestions for calibration strategy, define a procedure for project operation using the new lock and dam algorithms, define needed additions and changes to the GUI, discuss needs for migration of the system into the Water Control Data System modernization program in FY98, and develop milestones and responsible offices for the remaining tasks.

7-8 Jan. 1997 in the Missouri River Division. Technical meeting of the UNET specialists and water control personnel. Objectives of the meeting were to define modifications to the graphical user interface (GUI) needed in the final year of the MBMS project for timely completion and to review and modify the final milestone schedule proposed by OCE and HEC.

19-20 March 1997 at the Waterways Experiment Station. The objectives of this meeting were to review study status in light of the identified milestones (see report of the Jan. MBMS working group meeting in NWD-MR), define tasks necessary to meet the remaining milestones, and identify any problems (and their solutions).

Chapter 5

Data Development

5.1 Definition of Data

It is useful to categorize "data" into three types:

1. Input (or run) data: The data necessary to operate a numerical model such as UNET. Topographic information (cross sections) and flows entering/leaving the modeled reaches fall into this category.

2. Calibration data: Field data (measurements) used to evaluate the performance of a numerical model and adjust model parameters as necessary to obtain a better match with the measurements. Typically, observed flows and/or stages within the modeled reach are used for the MBMS calibration. Note, these observations may be anecdotal in nature (e.g., "This flood was higher than the flood of 1882.").

3. Verification data (also known as confirmation or circumstantiation data): Additional field data, not used in calibration, that are used to verify that the model performs adequately under conditions other than those for which it was calibrated. It is rare, when dealing with a complex river system such as the Mississippi-Missouri, that verification data will be available. It is incumbent upon the modeler to demonstrate that the results are credible and reliable.

Throughout this report, the specific meaning of the word "data" at any point is communicated either explicitly or via context.

5.2 Data Requirements

In addition to the categories of data described above, the quality and reliability of the data are of interest. It is important to note that all field data contains some degree of measurement error. A continuing area of concern that arose many times during the course of this study is the quantification of the relationship between higher accuracy topographic data and increased accuracy and reliability of the results computed from those data. This has been studied and documented for the use of HEC-2, a one-dimensional steady flow model (HEC, 1986). That study determined that the primary source of uncertainty in computed results was the estimation of energy loss coefficients, not topographic data accuracy using normal surveying standards at that time. Experience with one-dimensional unsteady flow models, such as UNET, has

confirmed and expanded that conclusion. It is important, in the application of an unsteady flow model, that storage as well as conveyance be properly represented. This requires accurate definition of the conveyance and the flow-controlling elevations and locations (e.g., levees, weirs, etc.). Ground elevations in storage areas such as overbanks and leveed areas are not as critical, if the volumetric capacity of those areas is correct. Information based on topographic maps with 1.5m (5 ft.) contours is usually adequate for overbank areas for systems with broad floodplains. When applying a two-dimensional flow model, however, the ground topography becomes more important, particularly in areas of little vertical relief. It was decided that 0.5m (2 ft.) vertical resolution was needed in the cross-over area between the Missouri and Mississippi Rivers for reliable two-dimensional modeling. This requirement depends on the relationship between water depth and bed elevation changes. When applying any of these hydraulic modeling approaches, one must be aware that there is substantial uncertainty in past inflows to the system as well as the forecasted inflows, all of which will influence the reliability of the computed results. Note however, that for the purposes of mapping and producing inundation displays, more detailed overbank topography may be useful.

5.3 Data Access and Use

Specific descriptions of the geographic coverage of the data, its content and use are given in separate Sections for each of the offices involved. Also covered in detail is the calibration process and results. As the data will continue to be updated, the local office remains the primary source for access to UNET input data. Analysis of modeling results and their dissemination are the purview of the performing office.

Chapter 6

Demonstration of the Modeling System

A demonstration of the operation of the UNET forecasting modeling system was held at Headquarters during July 15-17,1996. It involved three Districts; Rock Island, Kansas City and St. Louis. These were chosen because their interactions reflect the general needs for data transfer and boundary condition selections that will occur in a real time forecasting environment. Early in the development of the forecasting model, it was conceived to be a single model of the entire Missouri-Mississippi system; this was subsequently deemed impractical for several reasons. First, each District office has knowledge and experience that are unique and valuable to the accuracy, reliability and timeliness of their forecasts. Second, operation of a single, integrated model would be computationally much more cumbersome than performing data transfers between the individual offices. Third, by using a stage boundary condition between segments, the accumulation of numerical error is reduced. Also, response time to locally changing conditions, such as rapidly changing tributary inflows and (potential) levee breaches, will be quicker if the analysis is performed by the local office. The concept of model "overlap areas" that was developed in the FPMA study continued to be used in this effort. The purpose of these areas is to provide the hydraulic connectivity that couples the various segments of the UNET model together as if it were being run as a whole system. The three reaches, data transfer points and overlap areas that were selected for the demonstration are shown in Figure 6-1.

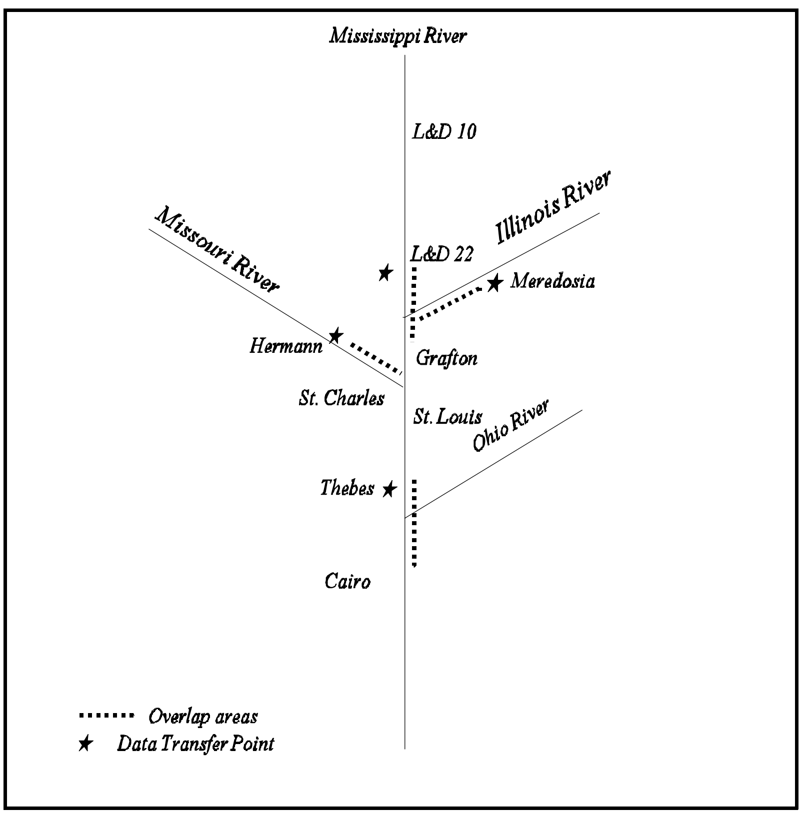

Figure 6-1. Schematic of the Area Used for the Model Demonstration.

In general, the location of the data transfer (i.e., the passing of the upstream forecast to the downstream office) is within the upstream District. The computational boundary condition used for the upstream District model is located at that District's downstream boundary. This overlap eliminates the influence of the downstream

boundary condition on computed results at the transfer location. Within the overlap area, both Districts use the same cross sections. Responsibility for forecasting local inflows within the overlap areas, if any, is that of the upstream District.

Preparation of the MBMS UNET model for the demonstrations took place at the Pulaski Building on the evening of July 14, 1996 and the morning of July 15, 1996. Field personnel presented an informal demonstration the afternoon of Monday, July 15, to headquarters Hydraulics and Hydrology Branch personnel. Along with introductory text and technical information, the demonstration included execution of the MBMS UNET model with 1993 Flood data for different reservoir release and levee scenarios. The purpose of this demonstration was to present the MBMS and its graphical user interface (GUI) to headquarters H & H staff, and to provide information and visual aids for H&H staff to use in the Command briefing the following morning. This demonstration also served as a practice session for the demonstration scheduled on July 17, 1996 for representatives of other Federal agencies.

Both the Command briefing and the demonstration for other Federal agencies were held in a large conference room in the office of the Chief of Engineers. The Command briefing was held on July 16, 1996. It was attended by General Genega and Corps executive staff members from Engineering Division. The progress, status and capabilities of the MBMS were very well received by General Genega and the Corps executive staff.

The MBMS was demonstrated to representatives of the NWS, USGS, FEMA, Federal Highway Administration, and Sun Microsystems (who loaned the computer for the demonstration) on July 17, 1996. One of the representatives of the NWS was Dr. Danny Fread, chief of their hydrology office. Dr. Fread said that he thought it was beneficial that the Corps had developed an unsteady flow model of the Mississippi Basin. He said the NWS is also working on an unsteady flow model, and communication and cooperation between the Corps and the NWS will be enhanced, since both agencies will be talking from the same basis. There were a few questions for more information following the demonstration. The reaction from the other agencies was positive and supportive of this effort.

Following is a brief summary of the components and sequence of the demonstration. First, H&H staff introduced the background, purpose, objectives, geographical coverage, and scope of the study; features of the UNET model; brief description of scenario examples; and current and future tasks of the study. The demonstration scenarios were then presented with HEC operating the graphical user interface (GUI) while the technical person from each District described the scenario being demonstrated. The parts of the GUI were explained. Scenarios that were demonstrated with a "live" run of UNET were: (1) Impact of increased releases from a reservoir (Truman) by NWK, (2) Impact of increased reservoir releases at St. Louis by MVS, and (3) Impact of changes in levee breach characteristics (Sny Levee District) by MVR. MVS discussed the effects at St. Louis of various changes in levee configurations due to overtopping and/or breaching upstream (Sny Levee District) and

downstream (Columbia Levee District) of St. Louis. The resulting flow and stage hydrographs computed with UNET were displayed and interpreted. WES discussed implementation of the 2-D model for the Missouri-Mississippi crossover area at St. Charles, Missouri and its connection to the MBMS UNET model. CECRL presented the coupling of MBMS results (water surface profiles computed by UNET) and GIS topography to produce inundation maps.

Chapter 7

Applications of the Modeling System

The St. Paul District (MVP) applied the system during the 1997 flood to forecast water surface elevations on the Mississippi River within the District and to provide the Rock Island District with predictions at Lock and Dam No. 10. The results of these forecasts were also furnished to MVP's Construction-Operations Division for emergency response activities. The results were also posted on the District's water control home page. Preparation of a UNET forecast, using the GUI, required about 20 minutes.

The Rock Island District (MVR) also used the MBMS during the spring flood of 1997. The accuracy of St. Paul District's forecast at Lock and Dam 10 and careful base calibration of the MBMS were key factors in the production of accurate forecasts. The MBMS was run daily by water control personnel from April 10, 1997 to May 7, 1997. This experience demonstrated both the accuracy and reliability of the MBMS in a real-time flood application.

The St. Louis District (MVS) tested the MBMS in May 1996 during a flood. It was noted that stages at St. Louis were underpredicted by about 2 ft. Further investigation revealed that a shift in the rating curve had occurred. After appropriate conveyance adjustments were made, the forecasted stages were within 1 ft. of the observed. As this was a test application, no further refinements were made. After further calibration, GUI development and implementation of Lock & Dam algorithms the MBMS was extensively used during the spring 1997 flood. Generally, the model results deviated from the observations by less than 1 ft. A file transfer system was used to obtain forecasts from MVR for the Mississippi R. and NWK for the Missouri R. MVS's forecasts were then delivered to LRD and MVD.

The Mississippi Valley Division (MVD) tested the MBMS during the 1997 flood. Because calibration was not completed at that time, the model was only used to forecast flows (not stages). The flow forecasts looked reasonable and were used to estimate the duration of the Bonnet Carre Spillway operation.

Chapter 8

Summary of Achievements
Relative to the Enabling Scope of Work

1. Improve and facilitate the coordination, communication and sharing of data and forecasts among water control activities along the mainstem Mississippi River during all hydrologic conditions ranging from low flows to floods. This can be accomplished through the use of a uniform and consistent channel routing model and data management/display system.

An integrated, uniform and reliable modeling system has been developed and implemented for all of the District offices involved in the Missouri-Mississippi Basin river flow and stage forecasting project. The components of this system are described in Sec. 2.3. The design of the system allows use of familiar software modules (e.g., UNET and HEC-DSS) operating under a common GUI with the integration of locally-developed utilities for data acquisition, manipulation and communication. This effort leveraged on past work (SAST and FPMA) to focus on forecasting, utilizing the available framework of data, software and experience. A prototype of the MBMS was demonstrated to Corps Engineering Division Executive staff and representatives of other Federal agencies in July 1996 (see Chapter 6). The success of this project is further evident in that the MBMS was used, on-line, in real-time, during flood events in the Mississippi River Basin in the Spring of 1997. The range of applications extended from assistance to emergency management to the estimation of the duration of operation of the Bonnet Carre spillway.

2. Assess impacts of levee breaching and floodway operations on local and downstream areas.

Tools were developed and implemented for the analysis of the impacts of levee breaches. That effort consisted of an analysis of pre-MBMS capability (Sec. 3.3.1), development and application of new algorithms reflecting both the conveyance and storage of the leveed areas, and detailed two-dimensional modeling of flows and stages in overbank areas (Sec. 3.5). Integration of the products of that effort into the real-time forecasting process requires off-line preparation of data descriptions that describe potential scenarios that can be activated at forecast time (see Sec. 3.3.1). A general analysis of the impacts of levee breaches and configurations was performed for the FPMA study.

3. *Support emergency management activities through timely prediction of stage and rate of rise.*

The MBMS computes both flow and water surface elevation as functions of time (both past and future) at locations of interest. The forecasts are dependent upon

predicted inflows to the system. Modifications to predicted inflows can be rapidly (10-20 min.) accommodated and the changed forecast disseminated to clients. This functionality was demonstrated during the Spring flood of 1997.

4. Display areal extent of flooding potential for various predicted weather scenarios and levee failures.

Software has been developed or modified to present hydrographs of both flow and stage to the forecaster reflecting various weather and levee breach scenarios. This information is of critical use for emergency response and was used during the 1997 flood. Corps of Engineer offices are using GIS technology based upon local data bases to blend the results of MBMS modeling with topographic information. The results of two-dimensional overbank flow modeling (Sec. 3.5) can be used to produce animated graphics of flooding.

5. Identify navigation hazards.

The MBMS was developed to simulate and forecast low-flow, routine day-to-day situations as well as those occurring during flood events (Sec. 1.1). A major developmental effort undertaken for this project produced the capability of the UNET system to simulate the operation of lock and dam structures (Sec. 3.3.3). These developments, combined with the modeling System's ability to route the impacts of lock and dam operational changes throughout the river system, allow the prediction and identification of resultant navigation hazards. The effectiveness of operational modifications proposed to alleviate those potential hazards can then be readily analyzed.

6. Provide data for real-time flood damage assessment.

A critical design component of the MBMS was the provision of data for post-forecast analysis. This primarily consists of providing information to potential users in readily accessible format. An important outcome of the MBMS implementation effort was the sharing of communication protocols and experiences among the District offices. HEC-DSS continues to be the backbone of data sharing and some offices are posting forecast information on their Web page. Interaction with the Water Control Data System Software Modernization R&D Program will continue to be the mechanism by which the products of the MBMS development project will become integrated into routine usage within the Mississippi Basin, Corps-wide and externally.

Chapter 9

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